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CHANNEL BEHAVIOR IN A PIEDMONT STREAM BELOW FLOOD WATER DETENTION STRUCTURES

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CHANNEL BEHAVIOR IN A PIEDMONT STREAM BELOW FLOOD WATER DETENTION STRUCTURES[1]

By Paul Yates[2]

INTRODUCTION

In the Piedmont region of the Southeastern States, major research is needed on channel behavior and on the carrying of sediment downstream. Specifically, the Soil Conservation Service has required criteria and guides for the planning, design, maintenance, and rectification of stream channels in this area. This publication describes the results of such a study in a middle Piedmont stream, Barber Creek, Georgia. Barber Creek watershed had recently received watershed protection and flood prevention treatment, including channel improvement and construction of flood detention reservoirs.

Purpose and Objectives

For a long time, researchers have needed to investigate more intensively the physical changes occurring in a channel downstream from newly installed flood prevention and sediment detention structures. This knowledge would enable them to predict developments under similar conditions. Channel shape, sinuosity, and stability may all be altered, because these structures change waterflow patterns, detain potential channel bed material, and disrupt bed material transport. These changes, which may be either desirable or undesirable, may occur as channel filling, bank widening, and bed scour. They may appear as variations in channel slope, roughness, and armor. Determining patterns of channel behavior at various distances downstream from flood control structures was the purpose of the studies discussed here.

The specific objectives were: (1) To study stream channel adjustments induced by changes in water and sediment discharge characteristics resulting from channel alterations, dams, and other modifying installations; (2) to develop procedures and guides for predicting channel changes; and (3) to study the interrelations of sediment concentrations and channel flow resistance with hydraulic and geometrical properties such as stage, discharge, width-depth ratio, and temperature.

Description and Location of the Watershed

Barber Creek (fig. 1) is located in Barrow and Oconee Counties, Ga. It flows into the Oconee River just south of Athens. Barber Creek drains a long, narrow watershed approximately 22 miles long and 3.5 miles wide. The drainage area of the channel studied is approximately 18,000 acres.

Located in the middle of the Piedmont Plateau, Barber Creek is quite typical of this region. This was a primary factor in selecting Barber Creek as the site for a major study. Parameters, which are so typical, include geology, soils, topography, land use, drainage, and climate.

Geology, Soils, and Topography

The principal rocks in the watershed include granite, syenite, granite gneiss, schists,

[1] Contributed by the Southern Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, in cooperation with the University of Georgia, College of Agriculture, College Experiment Stations.

[2] Research hydraulic engineer, Southeast Watershed Research Center, SWCRD, ARS, USDA, Athens, Ga.

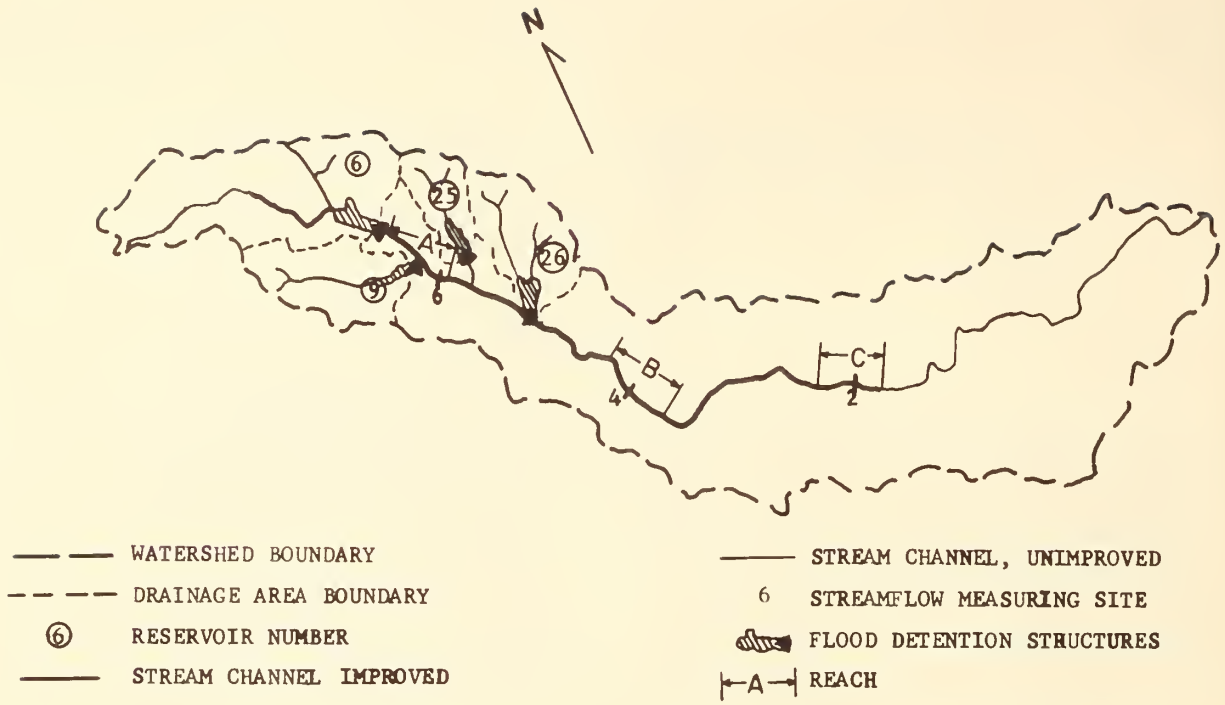

Figure 1.—Diagram of Barber Creek showing general location of reservoirs, gaging sites, study reaches, and channel improvements.

pegmatite, and quartz-mica schist of the Carolina series of Precambrian age. The depth to underlying rock varies greatly. There are some rock outcrops, including shoals, in the lower reaches of Barber Creek; in other areas, the rock may be very far below the surface of the watershed, sometimes as much as 100 feet.

Soils in the watershed are generally red and acid. They result from the weathering of underlying gneisses and schists. Predominant soil types are Cecil clay loam on the slopes, and Cecil sandy loam on the ridges. The alluvial soils of the flood plain are about equally mixed: sandy loams, silt loams, and silty clay loams. Because of poor management, most of these soils continue to be swampy.[3]

Topography ranges from undulating to gently rolling in the northwestern headwaters, and from rolling to hilly in the eastern part. Barber Creek Watershed becomes more hilly as the creek approaches its confluence with the Oconee River. Ridgetops are generally broad and smooth. The slopes are usually long and smooth, becoming steeper and more irregular as the creek approaches the Oconee River.

Drainage and Precipitation

The Barber Creek Watershed drainage pattern resembles the branches of a tree (dendritic). Major streams flow easterly or southeasterly. Because the maximum watershed width is only 3.5 miles, all tributaries drain a small area and, therefore, are rather short and narrow.[4]

Although many of the tributaries cease flowing during dry periods, Barber Creek is perennial. Small, underground streams feed the channel slowly but constantly, and four major flood-prevention reservoirs retain ample water to furnish a continuous discharge. This also greatly influences the flow regime of most storms. Most watershed soils have good drainage, with the exception of small, swampy areas in the flood plain. These swampy areas are caused by the poor management and neglect of landowners.

[3] Anonymous. Oconee River Soil Conservation District, County Government-Barrow County, County Government-Oconee County. Watershed Work Plan, Barber Creek Watershed-Barrow and Oconee County, 1957.

[4] See footnote 3.

Over a period of 80 years, precipitation has averaged about 50 inches annually. However, for the 4 years studied, rainfall could not be classified as typical. The 4-year average of 55.38 inches is very near the long-term average. However, 62.52 inches in 1963 was the greatest rainfall in 15 years. This was surpassed in 1964 by 72.48 inches, the second highest rainfall ever recorded in the Athens area. Only 35.82 inches were recorded in 1965, which makes this one of the 6 driest years on record.[5]

Land Management

Since 1945, cattle and poultry raising in the area has increased. There has been a corresponding reduction in row crops. As of 1957, estimates listed the following percentages of land use:[6]

Woodland	37.1
Crops	33.5
Pasture	20.8
Hay	4.5
Other	4.1

These values remained fairly constant during the study period.

Watershed Improvement

(P. L. 566 Project)

Barber Creek Watershed was one of the first improved under Public Law 566. Land was improved by cover crop, pasture, and hay seeding, tree planting, woodland management, farm drainage, waterway development, and roadside erosion control. Structural and engineering accomplishments included terrace and farm pond construction, the installation of four major dams (See table 1 for reservoir data), and channel improvement. This entailed dredging, clearing, or snagging nearly 11 miles of Barber Creek. Most of these improvements were made in the late 1950's and completed by 1960.

[5] U.S. Agricultural Research Service. Annual Research Reports of the Southern Piedmont Soil Conservation Research Center, Watkinsville, Ga. 1962, 1963, 1964, and 1965.

[6] See footnote 3.

Table 1.—Analysis of floodwater detention reservoirs

Reservoirs number	Drainage area	Floodwater detention pool surface area capacity		Sediment detention pool surface area capacity		Total capacity and floodwater sediment
	Acres	*Acres*	*Acre-feet*	*Acres*	*Acre-feet*	*Acre-feet*
6[1]	3,698	113	1,016	40	211	1,227
9[2]	1,333	47	422	14	76	498
25[2]	800	31	253	10	46	299
26[2]	1,321	51	418	13	75	493
Total	7,152	242	2,109	77	408	2,517

[1] On Barber Creek. [2] On Tributaries.

METHODS OF STUDIES

Sedimentology research concerned with national problems has been conducted at the Sedimentation Laboratory, Oxford, Miss., since 1956. In the late 1950's, studies demonstrated the need to extend the scope of the investigations to include channel conditions and the size of sedimentary material in the Piedmont area. To meet these needs, the research program of the Sedimentation Laboratory was extended in 1961 to Barber Creek. Three reaches were selected for intensive research.

Specific studies within each of these reaches included the following:

(1) Establishment of channel cross sections, with periodic resurveys to document changes.

(2) Installation and operation of streamflow measurement facilities in each reach.
(3) Periodic discharge measurements at all stages to establish stage-discharge relations.
(4) Suspended sediment sampling concurrent with measurements to establish stage-suspended sediment movement relations.
(5) Periodic bed material sampling and size distribution analysis.
(6) Measurement of water surface slopes for selected runoff events.
(7) Use of various field measurement data to calculate such hydraulic parameters as retardance coefficients.
(8) Use of all data obtained to define the interrelationships among various physical and hydraulic characteristics.

Study Reaches

Three study reaches and associated gaging-sampling sites were selected and established in 1961. Selections were made to have one gaging site predominantly controlled by reservoirs in the upper part of the channel improvement, one near midway, and one near the lower end of the improvement. Basic information on each is summarized in table 2.

The three reaches studied are shown in figure 1. Reach A, 5,045 feet long, extends downstream from the outlet of reservoir No. 6. This reach is situated in an area whose flood plain consists of about one-half improved pasture and one-half swampy, unimproved woods and thickets. Although this part of the channel was not dredged during P. L. 566 improvement work in 1958-60, some clearing and snagging were accomplished.

Reach B, 2,000 feet long, is located about halfway between Reach A and the lower part of the channel (just below Reach C) which had been improved in the original watershed program. Reach B, bisected by U.S. Highway No. 78 about 10 miles west of Athens, is part of the channel that was dredged in the late 1950's. Most of the flood plain in this area embraces swamps and unimproved woodland, but a small amount of pastureland is included.

Reach C, 1,200 feet long is located in the downstream part of the P. L. 566 improved channel. It was dredged around 1959. The flood plain in this area is very similar in use to that of Reach B.

Cross sections were established and monumented when the first surveys were made in June 1961. Nominally, cross sections were made at 100-foot intervals in Reaches B and C, and near each end of Reach A. Through the major part of Reach A, a spacing of cross sections of 500 feet was made. However, additional cross sections were made wherever local conditions seemed to warrant them. This could have been caused by stream curves or meanders, or by an apparently rapidly changing channel condition such as bank slough. These cross sections were resurveyed annually to document changes.

Gaging Stations

In the fall of 1961, gaging stations were established in each reach (fig. 2). Stilling wells were placed 10 to 15 feet from the channel, with three intake pipes from channel to well. A sand trap, consisting of a concrete box, with inside dimensions of 2′ x 2′ x 2′, was placed in the streambed in such a manner as to force all low flows through the trap before passing into the stilling well. This device captured practically all of the sediment which otherwise would have entered the well and created a laborious removal task. A removable top made cleaning this box very simple (fig. 3).

Table 2.—Description of study reaches

Reach	Length of reach	Cross sections	Gaging station	Drainage area	Drainage area controlled by reservoirs
	Feet	*Number*	*Number*	*Acres*	*Percent*
A	5,045	29	6	6,000	83
B	2,000	23	4	12,000	59
C	1,200	19	2	18,000	39

Figure 2.—Gaging station No. 6.

Figure 3.—Sand trap.

In December 1961, Stevens A-35 stage recorders were installed and activated.[7] Discharge measurements and suspended sediment sampling were normally made weekly at the time of recorder servicing. However, during periods of rainfall and increased waterflow, these operations were carried out throughout the rise and fall of the hydrograph.

Measurements were made while wading in the stream or, when depths became too great, from footbridges (fig. 2). Occasionally, flow spilled over banks, and measurements were then made from the highway bridge with a portable crane (fig. 4).

Water Surface Slopes

Water surface slopes were recorded whenever possible. Staff gages had been installed 500 feet apart in reasonably straight channel reaches. To insure better accuracy, two staff

[7] Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

Figure 4.—Portable crane.

gages were placed in opposite sides of the stream at each end of the study reach. In this manner, any possible error caused by a difference in transverse water surface elevations would be reduced.

Bed Material Sampling

Samples of bed material were obtained periodically, beginning in June 1961. During the first period, samples were taken at various depths as follows:

(1) Surface material only.
(2) The upper 6 inches.
(3) 6 to 12 inches.
(4) 12 to 15 inches.
(5) 15 to 18 inches.
(6) 18 to 21 inches.

Later samples were taken only of the upper 6 inches. Plans to take additional depth increment samples at a future date were canceled because dredging operations had completely disrupted the natural bed.

Samples were taken with a soil auger at three points on each cross section (both sides and middle). The same locations were always used—cross sections near the upper end, center, and lower end of all three reaches.

Pictorial Record

Numerous pictures were made during the studies to show original channel conditions, construction and installation details, mechanics of operation, streamflow, changes in channel and bank, channel vegetative conditons, and subsequent channel redredging.

RESULTS

General Observations

The four reservoirs have had a highly desirable effect on streamflow in Barber Creek. Instead of the normal pattern of sharp rises in water level with valley overflow in uncontrolled areas, stages now increase much more slowly to a lower maximum. This maximum stage may remain for a few hours or for several days, depending upon the amount of rainfall retained in the reservoirs, before slowly falling to a normal flow rate.

An example of this occurred when approximately 7 inches of rain fell during the afternoon of June 26, 1963. Peak discharge at Gage station No. 2 (downstream) did not occur until midmorning of the next day. Flow remained high, with stage still about 1 foot above normal at the time of the next rainfall on July 18. This was 21 days after peak flow. On June 28, 2 days after the 7-inch precipitation, the trickle tube spillway inlet at Reservoir No. 6 (on main channel) was approximately 8 feet beneath the water surface. Naturally, this pattern of slow rise and fall of stage does not apply during a localized, high-intensity thunderstorm.

Velocities

Relatively low water velocities have been the rule within Barber Creek, because the reservoirs store the potential flood flow. These low velocities and the accompanying lack of turbulence have had a highly desirable effect on channel behavior. Although no data are available from Barber Creek before enactment of the flood prevention and watershed protection program, visual comparison with uncontrolled watersheds in the area indicate much less damage to channels and adjacent land in the controlled watershed. Only on two occasions have average velocities for a complete measure-

ment been over 4 feet per second (f.p.s.), the maximum being 4.13 f.p.s. Average velocities of about 3.8 f.p.s. were measured for the greatest flow depths of approximately 6 feet. Streamflow data are summarized in tables 3 and 4.

Suspended Sediment

Suspended sediment samples were taken concurrently with discharge measurements by the equal transit rate (ETR) mehtod. The DH-48 hand sampler was used whenever wading measurements were made, and the D-49 suspended sampler was used at higher stages. No attempt was made to measure bed load.

Suspended loads varied widely for a given stage or flow rate. These fluctuations were controlled primarily by season, ground cover, and antecedent moisture conditions. As shown in figure 5, seasonal variation averages were much greater for both fine and coarse materials than for the combined values. Concentrations of fine materials averaged nearly 50 percent higher in summer than in winter. However, average sand concentrations were only about 40 percent as high in summer as in winter. Totals of fine materials plus sands, although displaying less variation than either component individually, were highest in spring and lowest in summer and fall.

Many times, turbidity was much higher at flow depths of 2 or 3 feet than between 4 and 6 feet. The type and duration of precipitation were probably responsible for this. In late spring or during summer, high-intensity thunderstorms on freshly cultivated drainage areas induced moderate flows with high sediment concentrations. In late winter or early spring, higher flows generally occurred as the result of periods of longer rainfall. Then, little or no freshly cultivated areas were available as sources for material for erosion.

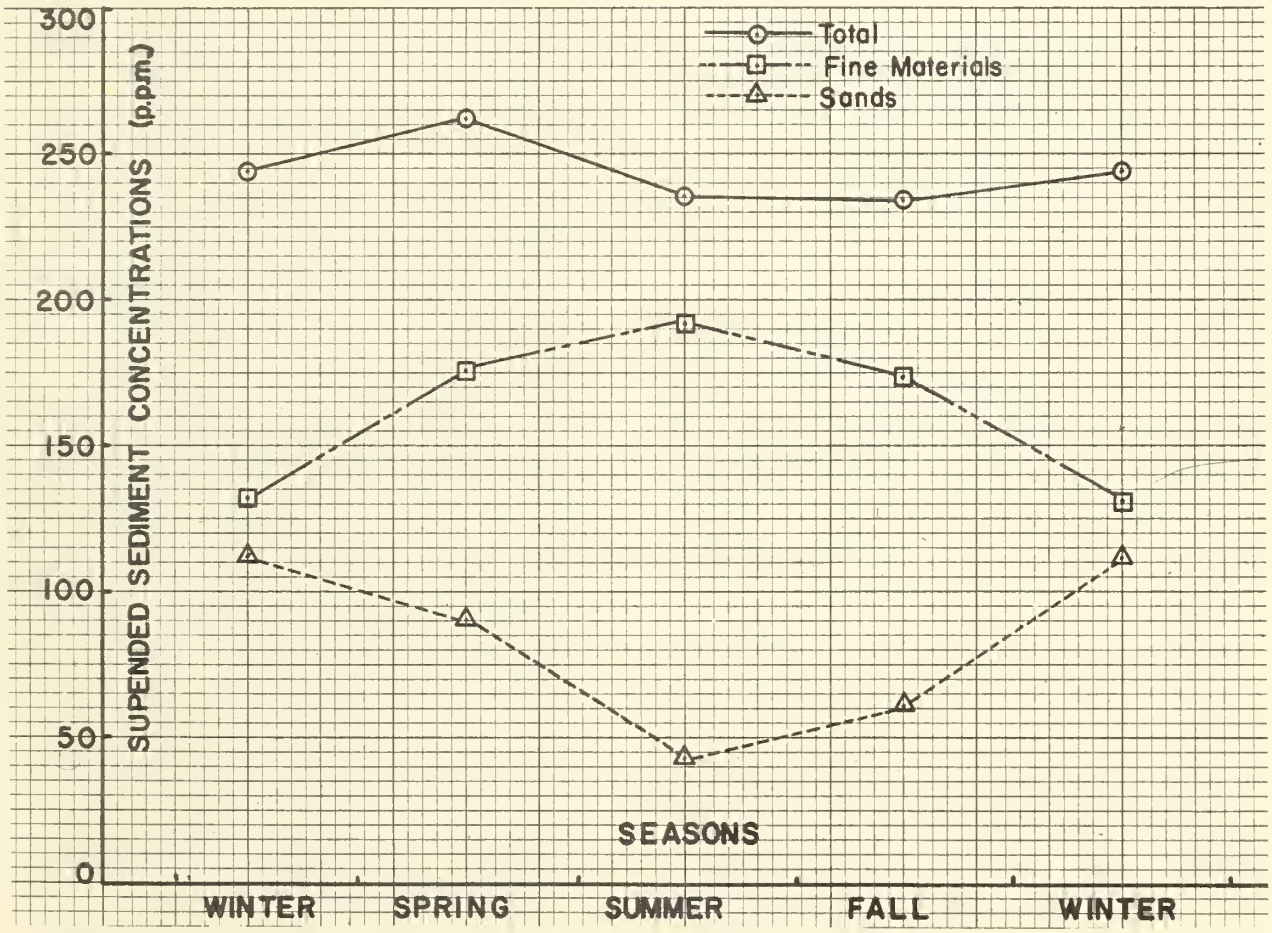

Figure 5.—Suspended concentrations by seasons.

Table 3.—Annual streamflow data summary for discharge

Station number	1962		1963		1964		1965	
	Maximum	Average	Maximum	Average	Maximum	Average	Maximum	Average
	C.f.s.	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*	*C.f.s.*
2	872	38.8	1,245	41.9	1,452	65.6	780	30.2
4	609	25.5	751	27.5	716	41.4	261	19.7
6	198	12.8	281	14.8	344	19.7	141	10.6

Table 4.—Annual watershed runoff

Station number	1962	1963	1964	1965
	Inches	*Inches*	*Inches*	*Inches*
2	16.12	20.17	31.69	14.56
4	15.95	19.90	30.00	14.20
6	16.17	21.42	28.70	15.32

During most runoff events, maximum sediment concentrations occurred on the rising side of the hydrograph. By the time the peak flow rate had been reached, most of the easily erodible material had already been removed. Therefore, sediment concentrations were considerably lower at maximum depths than at lower depths during the rise.

Turbidity ranged from a minimum of 4.1 parts per million (p.p.m.) to over 3,930 p.p.m. (table 5). Correspondingly, suspended sediment loads ranged from 0.01 to 1,448 tons per day. All these values are instantaneous rates only, not daily averages. A summary of instantaneous values of suspended loads is given in table 6. Table 7 summarizes yearly loads in tons per acre and total number of tons transported.

As indicated in figure 6, a direct relationship exists between the amount of sediment delivered annually per acre and the part of the drainage area controlled by flood control structures. For the range of controlled areas studied (39 to 83 percent), annual sediment delivery ranged from 0.57 to 0.30 ton per acre. Based on this relationship, as percentage of controlled drainage area doubles, sediment delivery values are reduced by approximately one-half.

The curve in figure 6 has been extrapolated to extremes of zero and 100 percent control, with delivery values of 1.0 ton/acre/year and 0.23 ton/acre/year, respectively.

Occasionally, suspended sediment samples were analyzed for size distribution. Samples chosen for analysis were fairly representative of the entire range of rates from base to peak flows. However, because of the small amounts of sediment obtained from low concentrations, base flow sampling seldom yielded sufficient material for a size distribution analysis. Those samples analyzed indicated a reduction in mean

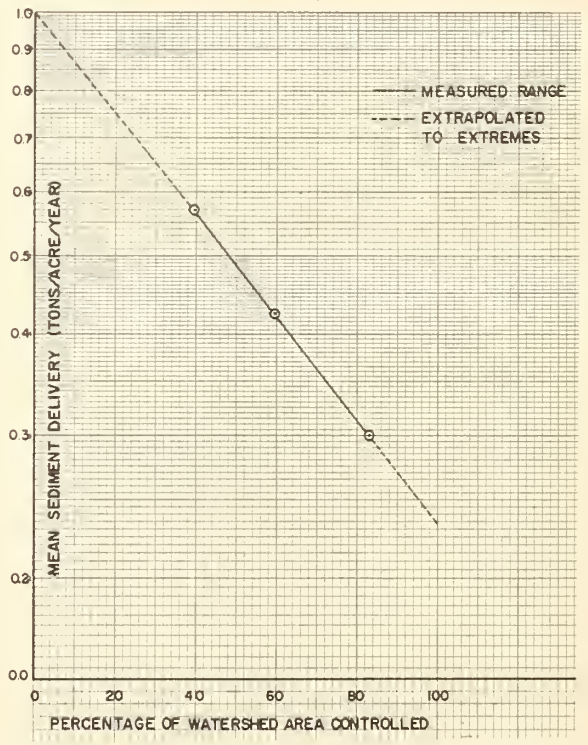

Figure 6.—Relationship of watershed area controlled to sediment delivery.

Table 5.—Range of suspended sediment concentrations (p.p.m. instantaneous values)

Station number	1962			1963			1964			1965		
	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
2	2,130	7.9	72.0	2,720	12	185	2,590	22	323	1,870	20	259
4	3,930	18.0	55.8	1,180	19	171	1,700	28	228	1,060	60	200
6	1,050	4.1	42.8	1,400	14	138	750	25	152	244	16	101

Table 6.—Range of suspended loads (tons per day, instantaneous values)

Station number	1962			1963			1964			1965		
	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
2	([1])	([1])	22.2	1,390	0.28	20.9	1,448	0.65	57.2	172.0	0.02	24.8
4	([1])	([1])	9.4	1,270	.38	12.7	556	.63	25.5	38.4	.06	12.6
6	([1])	([1])	3.1	840	.14	5.5	110	.34	8.1	59.8	.01	4.3

[1] Due to analysis techniques in 1962, only daily average values are available. Techniques modified with 1963 data to provide maximum and minimum values.

Table 7.—Yearly summaries of suspended loads

Station number	Total loads (tons)				Average loads (tons per acre)				
	1962	1963	1964	1965	1962	1963	1964	1965	1962-65
2	6,427	7,638	20,934	6,107	0.36	0.42	1.16	0.34	0.57
4	2,767	4,638	9,322	3,572	.23	.39	.78	.30	.43
6	932	2,020	2,972	1,162	.16	.34	.50	.19	.30

sizes with time. Table 8 shows this pattern. (D_{35}, D_{50}, D_{65} = material size at which 35, 50, and 65 percent, respectively, is smaller than the size shown.)

Table 8.—Size distribution of suspended materials (mm.) (Dredging period indicated by dashes)

Station	Date	D_{35}[1]	D_{50}[1]	D_{65}[1]
		Mm.	*Mm.*	*Mm.*
2	1962	0.0019	0.064	0.22
	1963	.0026	.010	.038
	([2])	([2])	([2])	([2])
	Dec. '63 - Mar. '64	.0050	.030	.135
	1964	.0016	.013	.125
4	1962	0.03	0.12	0.30
	1963	([3])	([3])	([3])
	([2])	([2])	([2])	([2])
	Dec. '63 - Mar. '64	.0023	.02	.135
	1964	.0016	.013	.120
6	1962	0.01	0.222	0.05
	1963	([3])	([3])	([3])
	Dec. '63 - Mar. '64	<.001	.0029	.02
	1964	<.001	<.001	.024

[1] D_{35}, D_{50}, and D_{65}—Material size at shich 35, 50, and 65 percent of the material is smaller than the size indicated.

[2] Dredging occurred between June 1963 sampling date and subsequent sampling date.

[3] No samples taken.

A supplemental suspended sediment sampling was briefly conducted. This involved taking point samples at various distances from the streambed to determine concentration and size distribution profiles. As shown in table 9, sizes decrease very rapidly as distances from the bed increase. A short distance above the streambed, there is a sharp break in total concentration. After this break, there is a much slower, but clearly defined reduction in turbidity. The data are shown more clearly in figures 7 and 8.

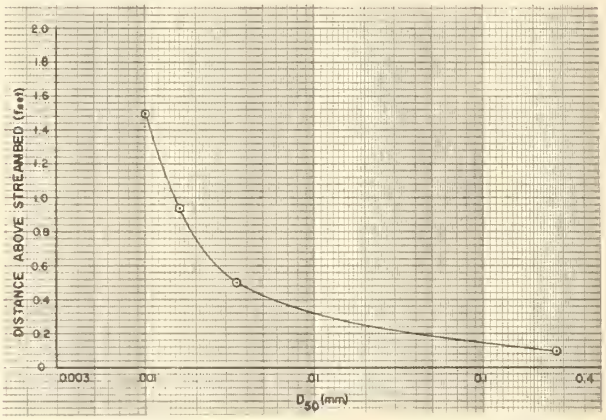

Figure 7.—Suspended sediment size distribution in flow profile.

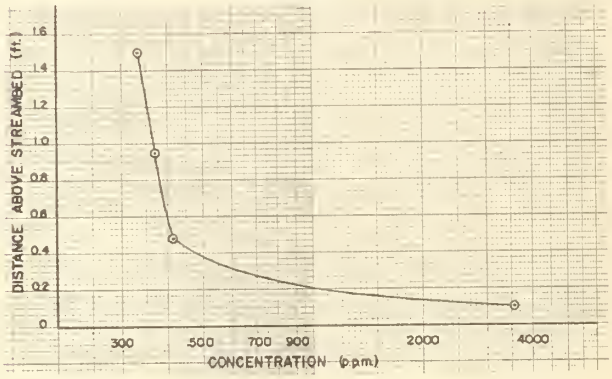

Figure 8.—Suspended sediment concentrations in flow profile.

Bed Material

Bed material sampling and size analysis began in June 1961. They were continued periodically until September 1965. Between June

Table 9.—Suspended sediment sizes at different distances above the steambed (Average water depth—2.35 feet.

Sampling distance above streambed (ft.)	Percentage distance from bed to surface	D_{35}	D_{50}	D_{65}	Concentration
		Mm.	*Mm.*	*Mm.*	*P.p.m.*
0.10	4	0.016	0.27	0.52	3,512
.49	21	.002	.004	.08	417
.94	40	.002	.002	.007	370
1.50	64	.002	.002	.002	332

1963 and September 1965, no attempt was made at bed sampling because of disturbances wrought by channel dredging in 1963 and 1964. Size analysis data are summarized in table 10. The inconsistent results for May 1962 were apparently caused by unsatisfactory sampling conditions. Samples were obtained at time of greater flow depths than on other occasions. Therefore, part of the fine materials may have been washed out during sampling, yielding a larger mean size value.

Table 10.—Size distribution of bed material

Reach and date	D_{35}	D_{50}	D_{65}
	Mm.	*Mm.*	*Mm.*
A (upstream):			
June 1961	0.72	1.20	2.62
Sept. 1961	.60	.97	2.70
May 1962	1.33	2.44	5.00
June 1963	.84	1.37	2.50
Sept. 1965	.58	.92	1.60
B (midstream):			
June 1961	.65	.82	1.08
Sept. 1961	.52	.68	.90
May 1962	.95	1.22	1.63
June 1963	.76	.96	1.28
Sept. 1965	.36	.48	.66
C (downstream):			
June 1961	.67	.87	1.24
Sept. 1961	.39	.66	.90
May 1962	.99	1.33	1.81
June 1963	.87	1.13	1.50
Sept. 1965	.37	.51	.71

During all sampling periods, the coarsest material was found upstream, while the finest material was in the middle reach (fig. 9). Within all three reaches, median sizes decreased between June and September 1961 (fig. 10). Results from June 1963, however, indicate that median sizes had increased beyond the original measurements. The May 1962 results described sizes even larger than the June measurements. Perhaps, sampling techniques were not satisfactory, or there might have been seasonal variations. In both instances, larger sizes occurred in June, when intensive land cultivation made more material available. Smaller sizes appeared in September.

Figure 11 presents the mean (D_{50}) sizes in millimeters plotted by the months when sampling was done. Additional sampling would be necessary to explain this approach satisfactorily.

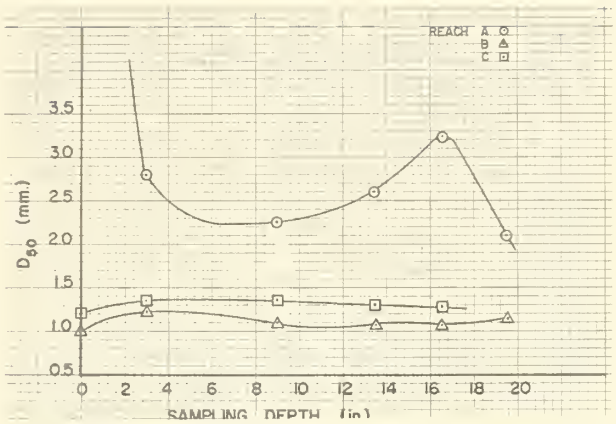

Figure 9.—Bed material size distribution with depth below surface.

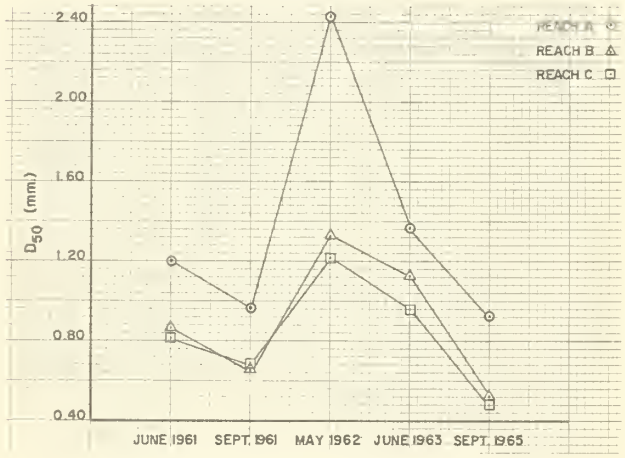

Figure 10.—Bed material sizes (D_{50}).

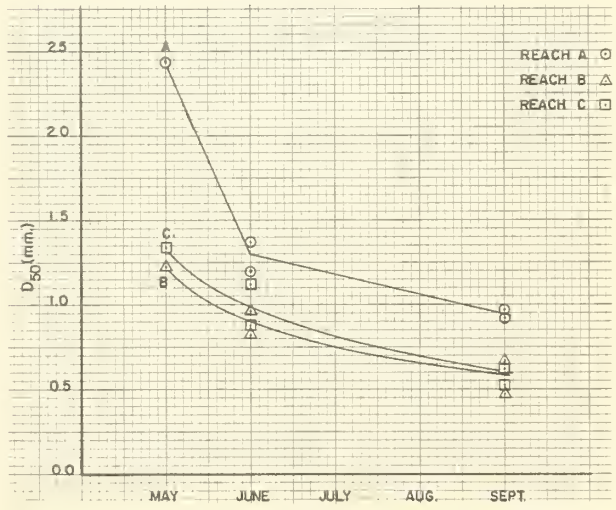

Figure 11.—Variations in bed material sizes (D_{50}).

During May 1962, samples were taken at various depths (table 11). Plans to repeat this procedure had to be abandoned because of supplemental channel dredging.

Size distribution within the profile apparently had no fixed pattern. The surface sample of Reach A held the coarsest material, but in Reach B, this sample contained the finest material. Similarly, Reach A had the finest material at the greatest sampling depth, in contrast to the finest material appearing at the surface of Reach B and Reach C. No definite depth-size relationship could be formulated in any reach.

Channel Stability

The selected cross sections were resurveyed periodically to determine what changes had occurred in channel geometry. Original surveying was conducted in June 1961. Subsequent surveys were made in June 1962, June 1963, February and November 1964, August 1965, and June 1966.

The results are presented in two parts. The first includes surveys until redredging in 1963 and 1964. The second part discusses results afterwards. The results before dredging are considered satisfactory. A postdredging recovery period was required to allow vegetation to reestablish itself on channel banks and to allow the channel to reach a slight degree of stability.

Between completion of the channel excavation in late 1964 and the latest surveying in June 1966, some degree of stability was reached. However, as cited earlier, 1965 was one of the driest years on record. Therefore, there was little opportunity to test the channel during higher flows. Additional surveys must be made to adequately define trends in channel stability after dredging.

Results before redredging.—According to John W. Roehl,[8] after a stream has had its previous source of sediment removed (for example, by construction of a detention structure), the stream has no alternative but to obtain transport material from its channel bed. Roehl speculates further that once the bed is cleared of materials to transport, the stream's energy is used to attack the banks to obtain material to satisfy its demand for a sediment load.

The results from Barber Creek studies tend to support these statements. As shown in table 12, bed scour or degradation occurred in the channel immediately below the upstream reservoirs. Apparently, some of this transported material was deposited in the middle part of the channel (figs. 12 - 14).

Degradation of 0.40 foot was measured in Reach A upstream, while aggradation of 0.14 foot was recorded in Reach B. Essentially no change occurred in Reach C. In other words, this time period was characterized by bed scour upstream, slight fill in the middle reach, and no significant change downstream.

Channel widening, or bank loss, occurred throughout the entire length of the channel. As shown in the second part of table 12, average bed widths for the three study reaches increased more than 1 foot. Top widths, shown

[8] Roehl, J.W. Sediment delivery ratios and the effect of structures on downstream channel contributions. Presented at ARS-SCS sedimentation workshop. Panguitch, Utah. 1962.

Table 11.—Bed material size distribution with depth below surface (May 1962)

Sampling depth (in inches)	Reach A		Reach B		Reach C	
	D_{35}	D_{50}	D_{35}	D_{50}	D_{35}	D_{50}
	Mm.	*Mm.*	*Mm.*	*Mm.*	*Mm.*	*Mm.*
Surface	1.62	11.80	0.82	1.00	0.94	1.20
Surface to 6 ...	1.35	2.80	.95	1.22	.99	1.33
6 to 12	1.25	2.25	.86	1.10	.98	1.33
12 to 15	1.35	2.60	.84	1.08	.94	1.30
15 to 18	1.50	3.25	.84	1.08	.91	1.27
18 to 21	1.18	2.10	.88	1.14	([1])	([1])

[1] Unable to sample at this depth in Reach C.

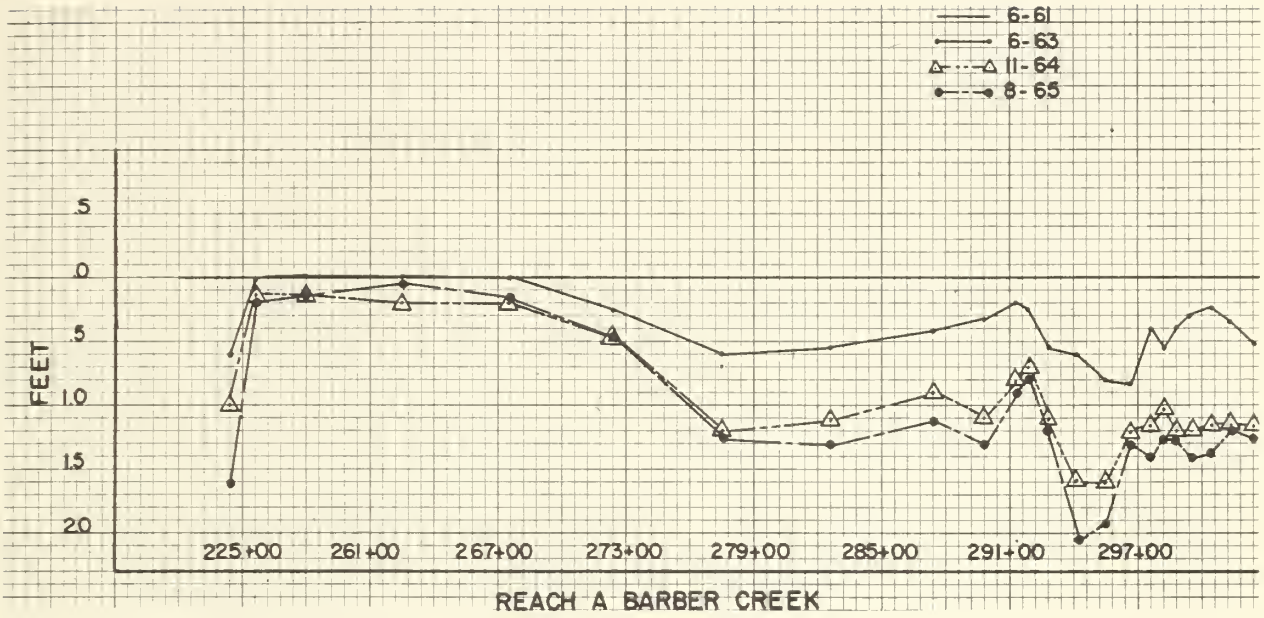

Figure 12.—Mean changes in bed elevation, Reach A.

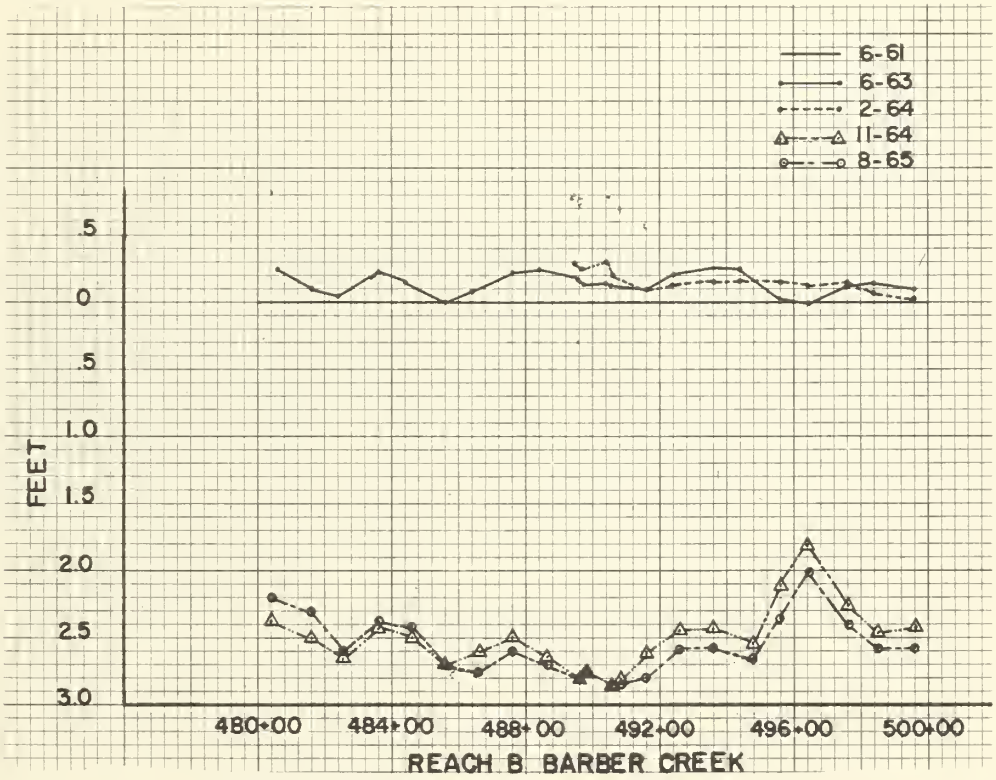

Figure 13.—Mean changes in bed elevation, Reach B.

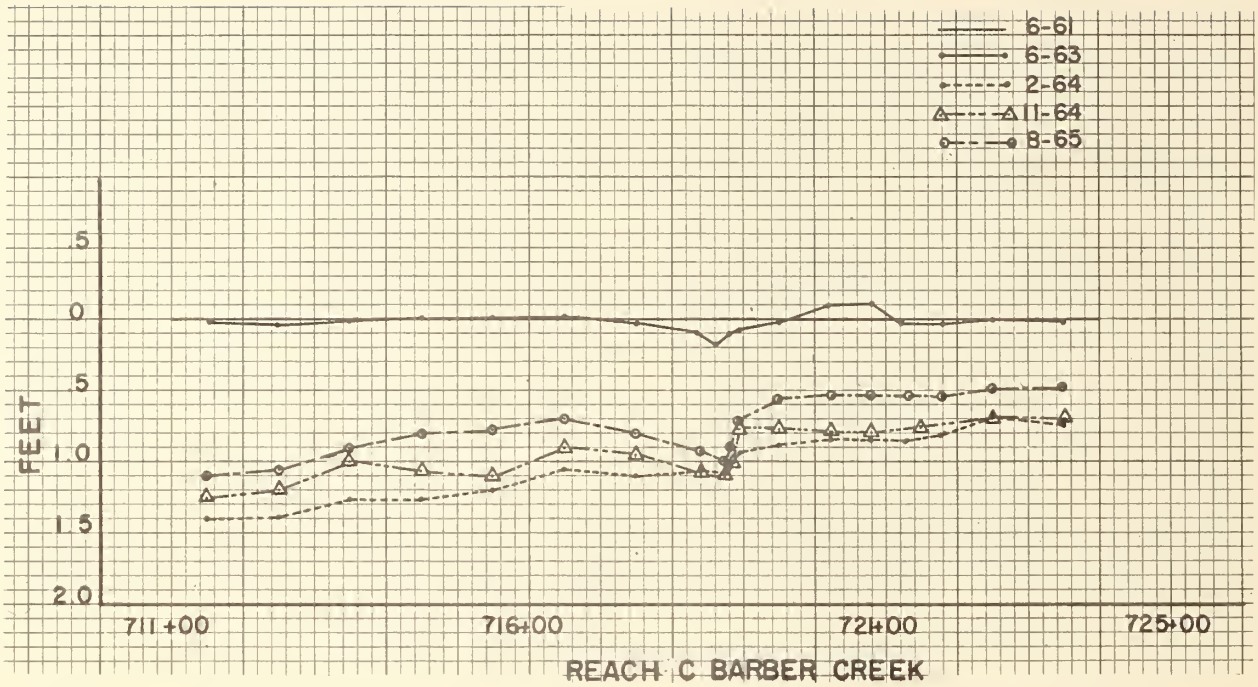

Figure 14.—Mean changes in bed elevation, Reach C.

Table 12.—Changes in channel cross sections, June 1961-June 1963

Dates (from June to June)	Reach A	Reach B	Reach C
	Feet	*Feet*	*Feet*
Average bed elevation:			
1961 to 1962	-0.34	+0.06	0
1962 to 1963	-0.06	+0.08	-0.03
Total change	-0.40	+0.14	-0.03
Average bed widths:			
1961 to 1962	+1.12	+1.11	+0.66
1962 to 1963	-0.37	+0.32	+0.24
Total change	+0.75	+1.43	+0.90
Average top widths:			
1961 to 1963	+1.30	+0.55	+1.86
	Sq. feet	*Sq. feet*	*Sq. feet*
Average changes in channel cross-sectional area:			
1961 to 1962	+5.60	+2.17	+0.74
1962 to 1963	+1.10	+1.19	-0.26
Total change	+6.70	+3.36	+0.48

in the third part of this table, increased more than bed widths.

In many spots, bank material sloughed off into the channel. Eventually, much of this material was carried downstream. However, at cross sections where slough material remained in place at the time of surveying, measurements were not necessarily a completely accurate indication of bed width. Cross sections were always resurveyed in the same spot, regardless of this slough material.

During normal flows at lower stages, there was a continual eroding action of slough material against the lower channel bank elevations. This eroding action gradually undercut the bank, leaving large, overhanging sections of bank material (fig. 15). Eventually, either because of high flows dislodging it or because it became too heavy (or both), this material broke loose and fell into the channel at the base of the bank (fig. 16).

Top widths enlarged even more than bed widths. This is apparent from table 12. This is evidence that the channel cross sectional area, or water-carrying capacity, increased throughout. Greatest increases occurred upstream in areas where bed scour was evident.

Because of this low flow erosive action, which sets the stage for greater and more dramatic bank material losses, consistent low flows are probably more damaging than the occasional higher flows.

Results after redredging.—Preliminary surveys were made at the same cross sections as before dredging. However, there had been a

Figure 15.—Bank undercut.

Figure 16.—Bank slough.

period immediately after dredging during which channel banks and bed attempted to achieve a condition of semi-equilibruim. Vegetation on banks had become fairly well reestablished to produce a more natural condition. Additional surveys should be made in the future to determine possible further channel changes.

Shifting Beds.—Because of bed shift, surveys taken one day might not give exactly the same results as those taken a few days, or even a few hours, later. This is illustrated by the following example. Streambed cross sectional profiles, as determined from four consecutive measurements, were plotted in figure 17. These measurements, covering slightly over 14 hours, were made June 23-24, 1964, during the recession of a moderate flow event. Average water depths during these measurements decreased from 3.58 feet to 0.84 foot. This example shows a continual movement of the streambed. Bed shapes across the stream during the highest measurements were irregular. However, these irregularities were fairly well smoothed out by the time of the lowest flow depth.

Although this illustration is based on one flow event, many similar plots could easily have been prepared. Persons engaged in stream gaging have often noticed the rapid changes in bed shapes during periods of measurement. Often, during a single runoff event, the greater flow depths may change from one side of the channel to the opposite side, and perhaps back to the original position again.

Similarly, bed conditions often changed greatly within a short time. By moving only 2 or 3 feet, stream gagers often moved from a very firm bed to an extremely soft one. At other times, one entire measurement might be made on a firm bed surface, while the next measurement was made almost entirely on a mushy bed. These changed bed conditions often occurred during consecutive measurements spaced only a few minutes apart.

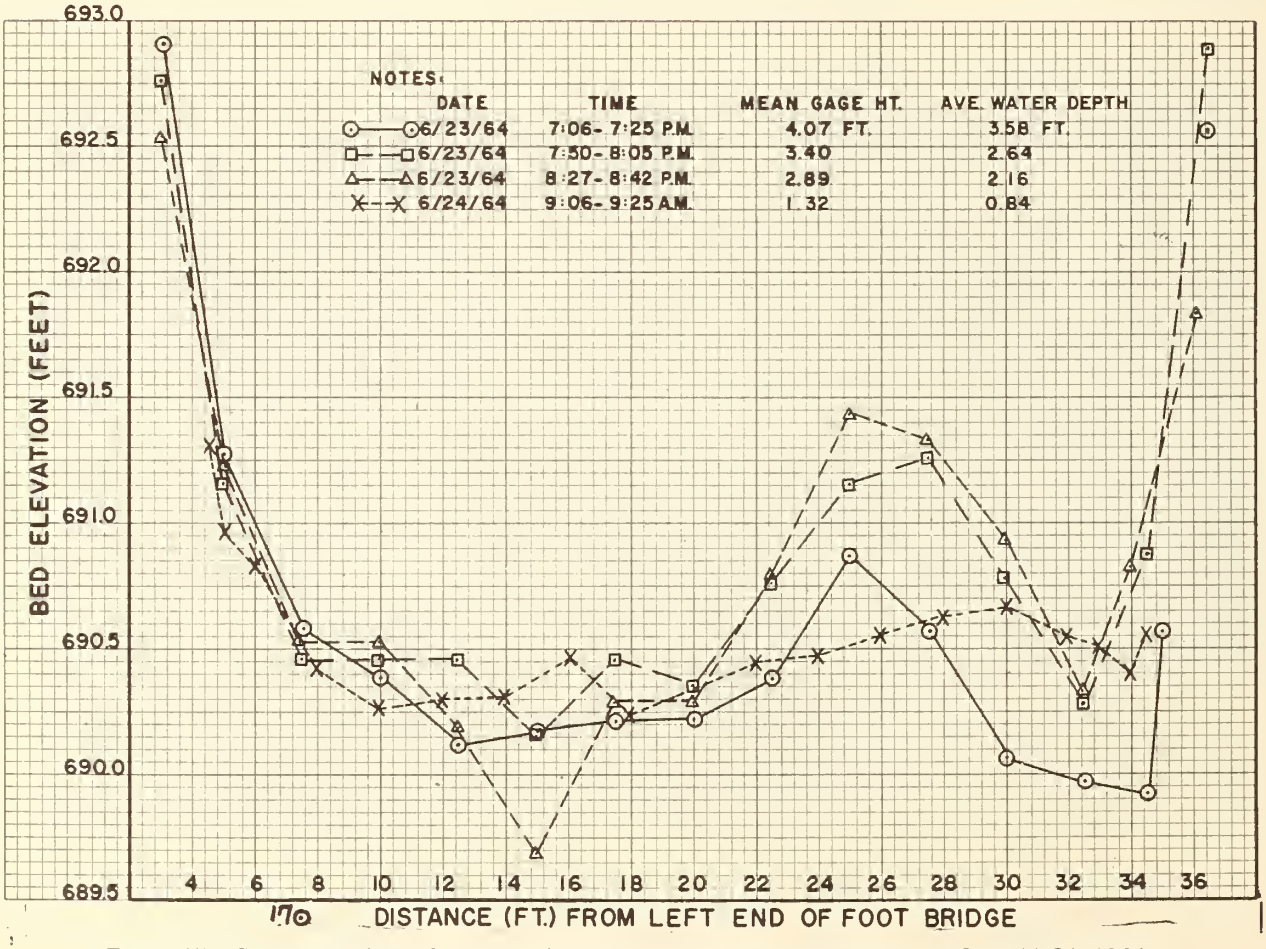

Figure 17.—Changes in channel cross section during consecutive measurements, June 23-24, 1964.

Resistance to Flow

As time permitted, staff gage readings were made to determine water surface slopes through a complete range of stages. Using these slopes and discharge measurement data, resistance coefficients (Manning's "n") were computed. Values of Manning's "n" were computed through a range of flow depths extending from less than 0.5 foot to slightly over 6 feet. The deeper depths occurred during overbank flows. All data used in calculations during these flooding periods were restricted to that cross sectional area between the banks and immediately above this area. All overbank flow was excluded.

For analysis purposes, "n" values were computed and averaged by 0.5-foot flow depth increments. Values of other variables were then averaged for the same flow depth increments. Values of Manning's "n" were plotted (fig. 18) against flow depths.[9] As may be seen from this graph, resistance values in Barber Creek were low at lower stages. As stream depth increased, these values gradually rose to maximum at approximately bankful stage. At this point they tended to decrease with further increases in flow. Values in this upper range are difficult to obtain because of the shortage of high flow measurements and the difficulty in separating overflow from channel flow. These trends were directly in constrast to the results usually obtained.[10] However, Chow stated that when banks are rough and grassy, "values may be higher at high stages." This is the case with Barber Creek.

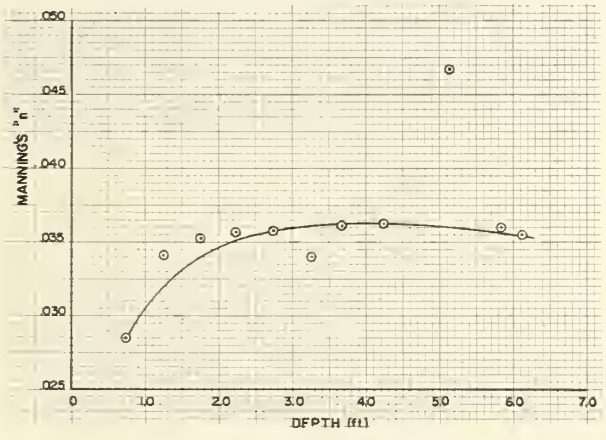

Figure 18.—Manning's "n" vs. flow depth.

The lower parts of the streambanks, in constant contact with flowing water, are fairly smooth and regular. Vegetation begins just above this normal water line. It increases in density and size with vertical distance up the streambank. Once the channel becomes full, additional depths of flow are in contact with adjacent flowing water rather than with additional vegetation. This water, naturally, offers little resistance, and the resistance value calculated for the entire channel cross section decreases accordingly.

Figure 19 illustrates the relationship between Manning's "n" and width to depth ratio.

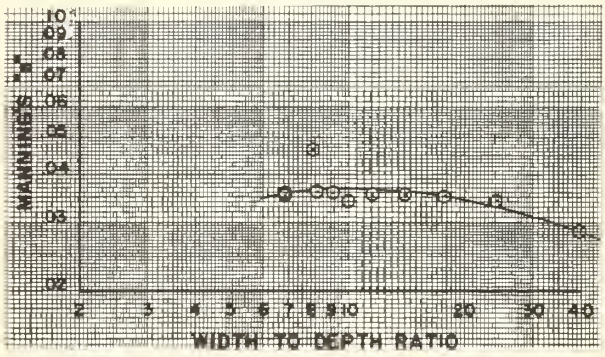

Figure 19.—Manning's "n" vs. width to depth ratio.

In this case we find a reversal of the trends discussed earlier. Because the ratio of width to depth decreases as depth increases, it would seem logical that retardance factors would decrease with increasing width to depth ratios. This would simply be another method of stating that "n" increases with increases in depth.

Seasonal flow rates varied widely, with corresponding fluctuations in flow depths and retardance factors. However, there was no change in the trends or relationship between Manning's "n" and other variables. Quantitative values changed seasonally, but there was no variation in the general relationships, or in qualitative values.

[9] Values plotted in figures 18 to 24 are combined averages from gaging station Nos. 2 and 4.

[10] Chow, V.T. Open channel hydraulics. McGraw-Hill Inc., New York. pp. 101-106. 1959.

Suspended Sediment Concentrations

As discussed earlier, water samples were obtained at all flow rates to determine the concentration of suspended material being transported. Samples were taken simultaneously with all discharge measurements. Turbidity usually was lowest at lowest discharge rates and lowest flow depths (fig. 20 and 21). Concentrations (turbidity) increased directly in proportion to increases in discharge and flow depths up to a point (approximately 500 to 600 c.f.s. and 4 to 5 feet, respectively). Beyond this point, concentrations generally decreased with further increases in flow rates or depths.

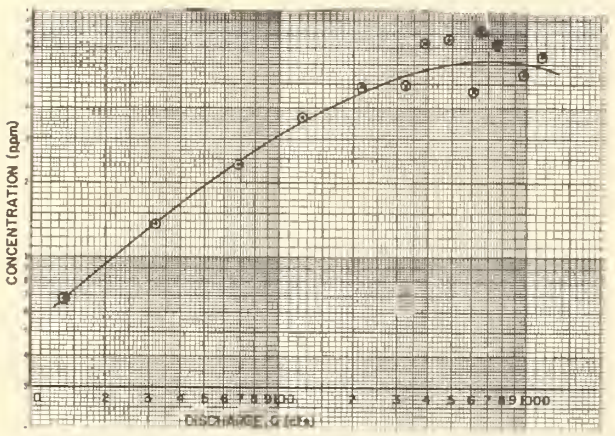

Figure 20.—Sediment concentration vs. discharge.

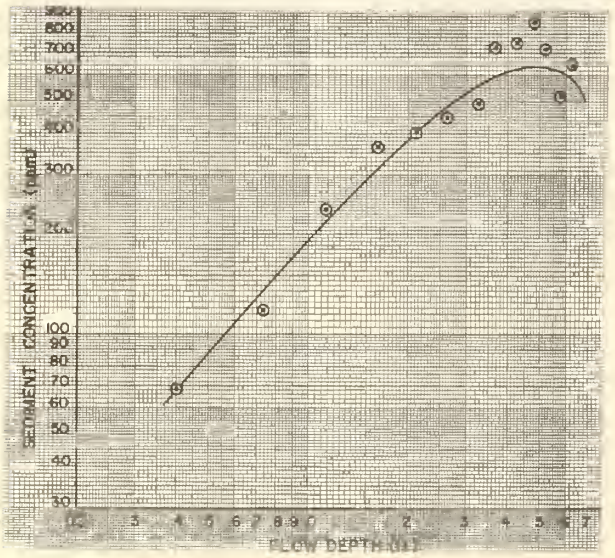

Figure 21.—Sediment concentration vs. flow depth.

Another method of expressing these results involves the relationship between peak discharge and peak suspended sediment concentrations. With very few exceptions, sediment concentration rose rapidly on the rising side of the hydrograph, and reached its peak a short time before peak discharge. Often, the highest concentrations were reduced by 50 percent or more by the time of peak discharge. This is illustrated graphically in figure 20. At a discharge of 400 to 500 c.f.s., concentrations approached 700 p.p.m. As discharge reached 600 c.f.s., concentrations ranged from 700 to 800 p.p.m. However, as discharge increased further to 900 to 1,000 c.f.s., concentrations diminished to 500 to 600 p.p.m.

Figure 22 presents essentially the same relationship as do figures 20 and 21. Hydraulic radius rose in direct proportion to increases in flow depth and discharge. Therefore, this is another demonstration of concentration increasing to a maximum before the peak of the independent variable, in this case the hydraulic radius, is reached.

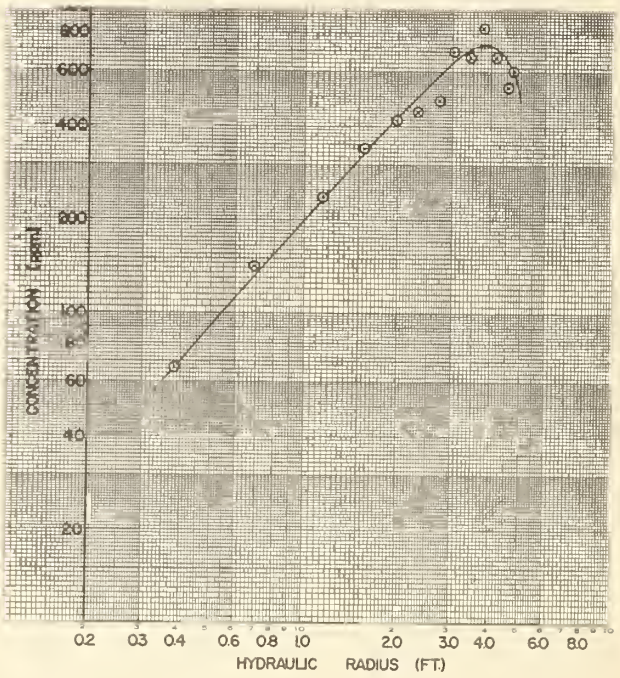

Figure 22.—Sediment concentration vs. hydraulic radius.

Results shown in figure 23, sediment concentration vs. velocity, closely approximate those of figures 20 and 21. Velocity tends to increase directly with increases in flow rates and flow depths. Therefore, similar results would be expected in each case.

Temperature was probably not an important factor in this study. Temperatures changed little, if at all, through any given storm

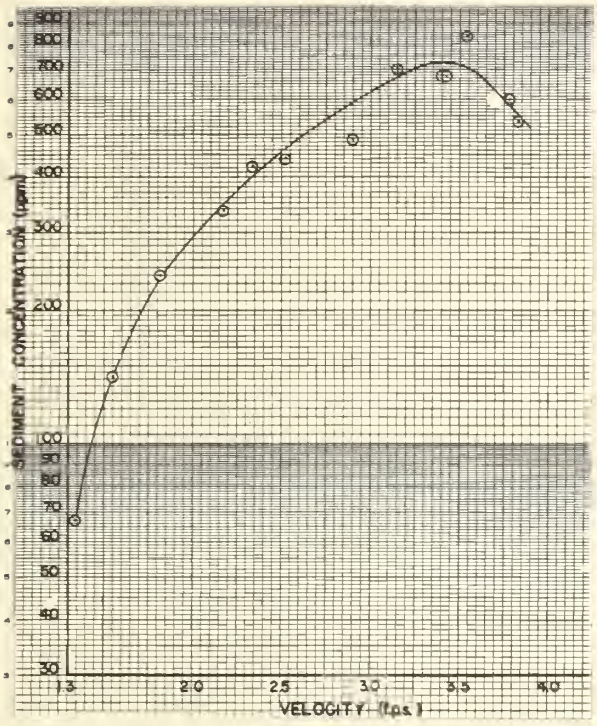

Figure 23.—Sediment concentration vs. velocity.

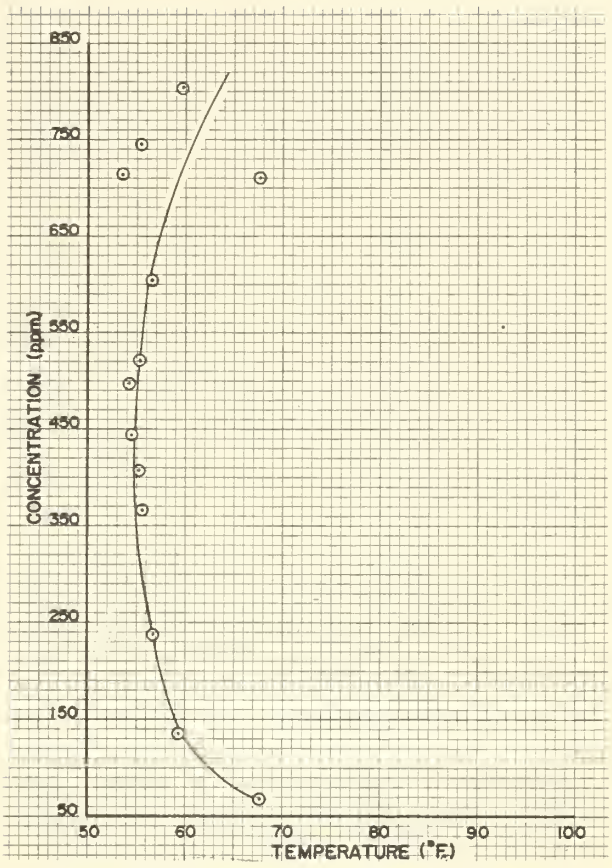

Figure 24.—Sediment concentration vs. water temperature.

because the reservoir storage helped maintain a near constant water temperature. Seasonal variations in temperature, of course, were very wide. However, the greatest seasonal variations in sediment concentrations were induced by changes in channel bank vegetation and watershed conditions rather than by temperature.

As shown in figure 24, the lowest and some of the highest suspended sediment concentrations occurred at higher temperatures. Results were similar for fine material, coarse material, and total concentrations. Maximum water temperatures were registered at very low flow rates, which occurred during the hot summer months. Naturally, little solid material was moved at these low rates. Hence, a high temperature—low turbidity relationship prevailed.

Similarly, the high-intensity summer thunderstorms, which generally produce some of the highest discharges, also cause the most extensive erosion damage. Occurring during periods of cultivation and exposed surfaces, these storms move a large quantity of material during the hottest period. This causes a high temperature-high turbidity relationship.

SUMMARY

Studies of streamflow, suspended sediment transport, and channel behavior in a Piedmont stream whose flow characteristics have been changed by channel alterations and dams were begun in Barber Creek, Ga., in 1961. The primary objectives were: (1) To study stream channel adjustments induced by changes in water and sediment discharge characteristics. These changes had resulted from channel alterations, dams, and other modifying installations. (2) To develop procedures and guides for predicting channel changes. (3) To study the interrelations of sediment concentrations and channel flow resistance with hydraulic and geometrical properties such as stage, discharge, width-depth ratio, and temperature.

Three study reaches were intensively surveyed and monumented at selected cross

sections. A stream discharge measuring and sediment sampling station was established and operated in each study reach. Discharge measurements and suspended sediment samples were taken at frequent intervals to ascertain accurately the total flow and total sediment carried in suspension for the period of record.

Selected cross sections were resurveyed periodically to determine any changes in channel geometry. Water surface slopes were recorded during some flow events, in order that retardance coefficients (Manning's "n") could be calculated. Bed material samples were collected occasionally and size distribution analyses made on these and on selected suspended sediment samples.

Channel behavior is summarized briefly as a pattern of bed degradation upstream, a slight fill in midstream, and essentially no change downstream. Widths increased consistently throughout the entire length of the channel, as bank material gradulally succumbed to the erosive forces of the flowing stream. Much of these losses was caused by slow but steady bank undercutting during low flow periods, and subsequent sloughing of large masses of bank material during higher flows. Total channel cross section areas increased throughout all reaches from upstream to downstream.

Retardance coefficients (Manning's "n") were calculated for depths ranging from base flow through bank overflow. Values of "n" were lower at low stages and gradually increased as stage increased. This trend held true until approximate bankful stage was approached. At this point, values began to decrease slightly.

This pattern of values of Manning's "n" increasing to a point where they remained fairly constant or gradually declined held true for other geometrical variables. The "n" values also tended to rise with increasing suspended sediment concentrations to a maximum value. After peaking, they remained fairly constant. The probable explanation is that peak sediment concentrations generally occur before peak discharge rates (or peak flow depths). Therefore, as "n" values continue to increase with increases in sediment, or as "n" values begin to decrease at peak flow rates and at bank overflow, there is a balance between the two variables (flow rates and sediment concentration). This produces a constant value of "n" at the higher concentrations of sediment. As described earlier, turbidity increases as stage increases, until at some point prior to peak discharge, turbidity begins to decrease.

Because reservoir storage helped to maintain a near constant temperature during a single storm period or flow event, temperature effects for this study were insignificant. Both the lowest and some of the highest turbidities were measured at high water temperatures of the summer months; low sediment concentrations occurred during summer base-flow periods and high concentrations resulted from high-intensity summer thunderstorms.

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